

# CHAPTER 3

## GENERATORS

### INTRODUCTION

As a Construction Electrician, you may have the responsibility for the installation, maintenance, and repair of electrical power generation equipment. In time of war or national emergency, Advanced Base Functional Components (ABFC) will normally be used at temporary overseas bases. Even in peacetime, generation equipment is used at remote bases or as emergency and backup power on most naval bases.

A power distribution system includes all parts of an electrical system between the power source and the load. This chapter gives the correct procedures for the operation and maintenance of power plants and distribution systems and presents technical information for the selection and installation of power-generating plants.

### POWER GENERATION

The characteristics built into naval electrical installations are simplicity, ruggedness, reliability, and flexibility to permit continued service. It is the function of those who operate these plants to make full use of the installation's inherent capabilities and to maintain, as far as possible, uninterrupted availability of electrical power where it is needed. To be able to do this, operating personnel should possess the following:

- A thorough knowledge of how to operate and maintain the components of an electrical plant
- A complete familiarity with the electrical plants distribution capabilities
- An understanding of the electrical system operation of the base
- The ability to apply electrical and electronic principles to specific installations
- The sizing and installation of secondary conductors

### EMERGENCY/STANDBY POWER

When you set up an emergency/standby power system, numerous factors must be considered. The following text will cover a few of the possible

situations you may encounter. This chapter does not include the automatic transfer aspect of switching to backup power, since this task is performed by someone with a Navy Enlisted Classification (NEC) code, CE-5601 Uninterruptible Power Supply (UPS). For our discussion in this section, we will be using the term emergency-the concepts involved are equally applicable to "standby" systems. Remember that the National Electrical Code® requires emergency and standby systems to be kept entirely separate from all other wiring and equipment. For more detailed information, see article 700 of the National Electrical Code®.

### SYSTEM DESIGN

Whether you are designing and installing an emergency backup system or operating and maintaining an existing system, you must be completely familiar with the installation requirements and the physical characteristics of the equipment. The design, material, and installation must comply with electrical safety standards and codes.

In general, when emergency power is discussed, it is assumed to be replacing "normal" power. The choice of arrangement and the size and the type of equipment depend in large measure on the loads to be fed from the emergency system. The system includes all devices, wiring, raceways, transfer switch, energy source, and other electrical equipment required to supply power to selected loads. These selected loads will be determined by the available power from your emergency power source. Figures 3-1 and 3-2 show two possible arrangements for emergency/standby power hookups.

### GENERATOR SELECTION

When an overseas base is first established and electrical power is required in a hurry, you will not have time to set up a centrally located generating station; instead, you will spot a portable plant at each important location requiring power. Table 3-1 lists some of the standard alternating current (ac) generators available. These standard generators are capable of meeting the power requirements of advanced bases and also those for permanent or portable emergency power.

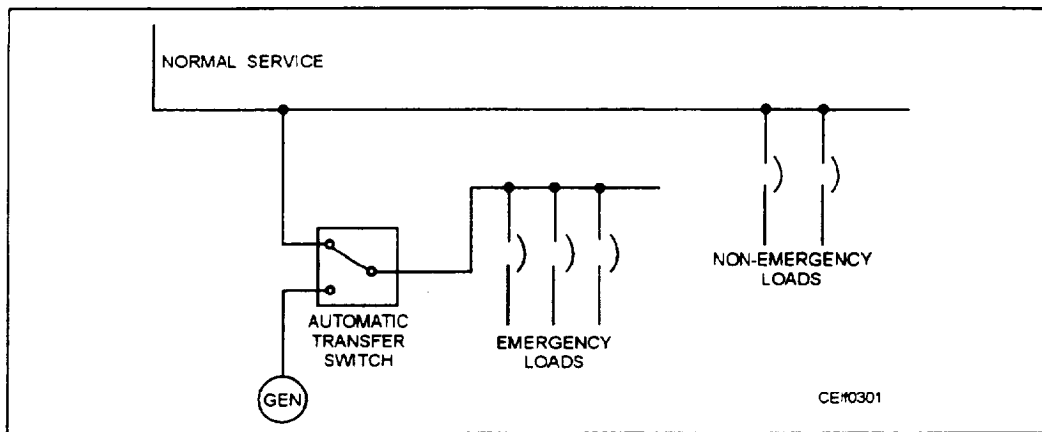


Figure 3-1.—Single-transfer switch.

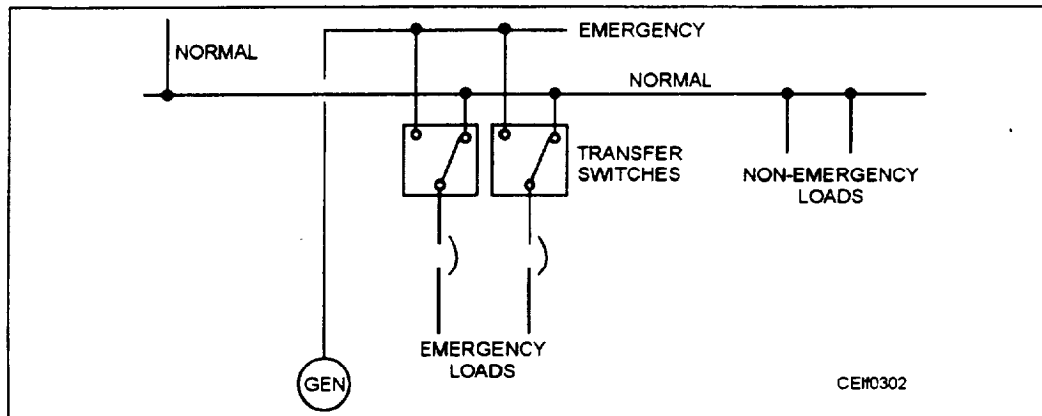


Figure 3-2.—Multiple-transfer switches.

The electrical loads to be supplied power, voltage, phase, frequency, and duty cycle requirements govern the selection of generating equipment. Probable load deviation, probable life of the installation, availability of fuels, and availability of skilled personnel are other important factors.

Electrical plants at advanced bases serve a varied load of lighting, heating, and power equipment, most of which demand power day and night. The annual load factor (the ratio of average power to peak power) of a well-operated active base should be 50 percent or more with a power factor (explained later in this chapter) of 80 percent or higher. If the load is more than a few hundred feet from the power source, a high-voltage distribution system may be required.

If several generators are to serve primary distribution systems, they should generate the same voltage to avoid the need for voltage transformation. The number of phases required by the load may differ from that produced by the generator. As loads usually can be divided and balanced between phases, most generators of appreciable size are wound for three-phase operation.

## Power and Voltage Requirements

The selection of voltage is affected by the size, the character, and the distribution of the load; length, capacity, and type of transmission and distribution circuits; and size, location, and connection of generators. Practically all general-purpose lighting in the United States and at United States overseas bases is 120 volts. The lighting voltage may be obtained from a three-wire, 120/240-volt, single-phase circuit or a 120/208-volt, three-phase, four-wire circuit.

Small motors can be supplied by single-phase ac at normally 120 volts. Large three-phase, ac motors above 5 horsepower generally operate satisfactorily at any voltage between 200 and 240. The use of combined light and power circuits will be accomplished by the use of 240- or 208-volt systems.

## Computation of the Load

As mentioned earlier in this chapter, there are various factors that must be taken into consideration in the selection of the required generating equipment. The following technical data will help you in computing the load.

**Table 3-1.—Types of Portable Generators**

	<b>Alternating current</b>					
<b>Frequency</b>			60-hertz			
<b>Voltage</b>	120		120/208		120/208 240/416	
<b>Phase</b>	1		1 & 3		3	
<b>Wires</b>	2		4*		4	
<b>Fuel</b>	G	D	G	D	G	D
<b>kW Rating</b>						
<b>5</b>	X		X	X		X
<b>10</b>			X	X		
<b>15</b>			X	X		
<b>30</b>				X		X
<b>60</b>				X		X
<b>100</b>				X		X
<b>200</b>						X
G—Gasoline driven. D—Diesel driven. *—Panel connections permit, at rated kW output: 120/208V 3-phase 4-wire, 120V 3-phase 3-wire, 120V single-phase 2-wire, 120/240V single-phase 3 wire.						

Before any part of the system can be designed, the amount of power to be transmitted, or the electrical load, must be determined. Electrical loads are generally measured in terms of amperes, kilowatts, or kilovoltamperes. In general, electrical loads are seldom constant for any appreciable time, but fluctuate constantly. In calculating the electrical load, you must determine the connected load first. The connected load is the sum of the rated capacities of all electrical appliances, lamps, motors, and so on, connected to the wiring of the system. The maximum demand load is the greatest value of all connected loads that are in operation over a specified period of time. Knowledge of the maximum demand of groups of loads is of great importance: because it is the group maximum demand that determines the size of generators, conductors, and apparatus throughout the electrical system.

The ratio between the actual maximum demand and the connected load is called the **DEMAND FACTOR**. If a group of loads were all connected to the supply source and drew their rated loads at the same time, the demand factor would be 1.00. There are two main reasons why the demand factor is usually less than 1.00. First, all load devices are seldom in use at the same time and, even if they are, they will seldom reach maximum demand at the same time. Second, some load devices are usually slightly larger than the minimum size needed and normally draw less than their rated load. Since the maximum demand is one of the factors determining the size of conductors, it is important that the demand factor be established as closely as possible.

The demand factor varies considerably for different types of loads, services, and structures. The National Electrical Code<sup>®</sup>, Article 220, provides the requirements for determining demand factors. Demand factors for some military structures are given in table 3-2.

Example: A machine shop has a total connected load of 50.3 kilowatts. The demand factor for this type of structure is taken at 0.70. The maximum demand is  $50.3 \times 0.70 = 35.21$  kilowatts.

## GENERATOR INSTALLATION

Generators are not permitted to be closer than 25 feet to a load; however, in setting up the generator, try to place the equipment near points of large demand to reduce the size of wire required; to hold the line losses to a minimum, and to afford adequate voltage control at the remote ends of the lines.

Moving the generator may be accomplished by lifting or pulling. The generator set comes equipped with a lifting sling usually stored in the skid on the side of the unit opposite the operator's control panel.

### Site Selection

You should study a plot or chart of the area on which the individual buildings and facilities have been plotted. The site you select should be large enough to meet present and anticipated needs. Then select a location where there will be sufficient space on all sides for servicing and operation of the unit. It should be level, dry, and well drained. If this type of site is not available, place the generator set on planks, logs, or other material for a suitable base foundation.

Table 3-2.—Demand Factor

Structure	Demand Factor
Housing	0.9
Aircraft maintenance facilities	.7
Operation facilities	.8
Administrative facilities	.8
Shops	.7
Warehouses	.5
Medical facilities	.8
Theaters	.5
NAV aids	.5
Laundry, ice plants, and bakeries	1.0
All others	.9

## Sheltering of Generators

Although advanced base portable generators are designed to be operated outdoors, prolonged exposure to wind, rain, and other adverse conditions will definitely shorten their lives. If the generators are to remain on the site for any extended period of time, they should be mounted on solid-concrete foundations and installed under some type of shelter.

Presently, there are no predrawn plans for shelters for a small advanced base generating station. The shelter will be an on-the-spot affair, the construction of which is determined by the equipment and material on hand plus your ingenuity and common sense.

Before a Builder can get started on the shelter, you will have to inform him of such things as the number of generators to be sheltered; the dimensions of the generators; the method of running the generator load cables from the generator to the distribution system outside the building; and the arrangement of the exhaust system, radiator discharge, and cooling air. Installation specifications are available in the manufacturer's instruction manual that accompanies each unit. Be sure to use them. Appropriate consultation with the Builder regarding these specifications may help minimize various installation and piping problems and costs.

The following hints and suggestions also will be helpful:

1. Ventilation is an important factor to consider when you are installing the units inside a building. Every internal combustion engine is a HEAT engine. Although heat does the work, excess amounts of heat must be removed if the engine is to function properly. Heat can be removed by setting the engine radiator grille near an opening in the wall and providing another opening directly opposite the unit. In this manner, cool air can be drawn in and the hot air directed outdoors. These openings can be shielded with adjustable louvers to prevent the entrance of rain, sand, or snow. In addition, when the engine is operating in extremely cold weather, the temperature in the room can be controlled by simply closing a portion of the discharge opening. Additional doors or windows should be provided in the shelter if the plants are installed in localities where the summer temperatures exceed 80°F at any time.

2. Working space is another consideration. Be sure to provide sufficient space around each unit for repairs or disassembly and for easy access to the generator control panels.

3. The carbon monoxide gas present in the exhaust of the engine is extremely poisonous. Under no circumstances should this gas be allowed to collect in a closed room; therefore, means have to be provided to discharge the engine exhaust to the outdoors. Exhaust can be vented by extending the exhaust pipe through the wall or roof of the building. Support the exhaust pipe and make certain that there is no obstruction and avoid right-angle bends, if possible. Also, whenever possible, arrange the exhaust system so that the piping slopes away from the engine. In this way, condensation will not drain back into the cylinders. If the exhaust pipe should have to be installed so that loops or traps are necessary, a drain cock should be placed at the lowest point of the system. All joints have to be perfectly tight; and where the exhaust pipe passes through the wall, you have to prevent the discharged gas from returning along the outside of the pipe back into the building. Exhaust piping inside the building has to be covered with insulation capable of withstanding a temperature of 1500°F.

After the generating units have been set in place and bolted down, Builders then can proceed to erect the building, using the necessary information provided by the CEs.

### Generator Set Inspection

After setting up a portable generator, your crew must do some preliminary work before placing the generator in operation. First, they should make an overall visual inspection of the generator. Have them look for broken or loose electrical connections, bolts, and cap screws; and see that the **ground terminal wire (No. 6 AWG minimum ) is properly connected to the ground rod/grounding system**. Check the technical manual furnished with the generator for wiring diagrams, voltage outputs, feeder connections, and prestart preparation. If you find any faults, you should correct them immediately.

### Generator Connections

When you install a power plant that has a dual-voltage alternator unit, make certain that the stator coil leads are properly connected to produce the voltage required by the equipment.

Proper grounding is also a necessity for personnel safety and for prevention of unstable, fluctuating generator output.

**INTERNAL LEADS.**—The voltage changeover board permits reconnection of the generator phase

windings to give all specified output voltages. One end of each coil of each phase winding runs from the generator through an instrumentation and a static exciter current transformer to the reconnection panel. This routing assures current sensing in each phase regardless of voltage connection at the reconnection board assembly. The changeover board assembly is equipped with a voltage change board to facilitate conversion to 120/208 or 240/416 generator output voltage. Positioning of the voltage change board connects two coils of each phase in series or in parallel. In parallel, the output is 120/208; in series, the output is 240/416 volts ac. The terminals on the changeover board assembly for connection to the generator loads are numbered according to the particular coil end of each phase of the generator to ensure proper connections.

Remember that you are responsible for the proper operation of the generating unit; therefore, proceed with caution on any reconnection job. Study the wiring diagrams of the plant and follow the manufacturer's instructions to the letter. Before you start the plant up and close the circuit breaker, double-check all connections.

**GROUNDING.**—It is imperative that you solidly ground all electrical generators operating at 600 volts or less. The ground can be, in order of preference, an underground metallic water piping system, a driven metal rod, or a buried metal plate. A ground rod has to have a minimum diameter of 5/8 inch if solid and 3/4 inch if pipe, and it has to be driven to a minimum of 8 feet. A ground plate has to be a minimum of 2 square feet and be buried at a minimum depth of 2 1/2 feet. For the ground lead, use No. 6 AWG copper wire and bolt or clamp it to the rod, plate, or piping system. Connect the other end of the ground lead to the generator set ground stud.

The National Electrical Code® states that a single electrode consisting of a rod, pipe, or plate that does not have a resistance to ground of 25 ohms or less will be augmented by additional electrodes. Where multiple rod, pipe, or plate electrodes are installed to meet the requirements, they are required to be not less than 6 feet apart.

It is recommended that you perform an earth resistance test before you connect the generator to ground. This test will determine the number of ground rods required to meet the requirements, or it may be necessary to construct a ground grid.

## Feeder Cable Connections

While the electric generator is being installed and serviced, a part of your crew can connect it to the load. Essentially, this connection consists of running wire or cable from the generator to the load. At the load end, the cable is connected to a distribution terminal. At the generator end, the cable is connected either to the output terminals of a main circuit breaker or a load terminal board. Before the wires are run and connections are made, it will be up to you to do the following:

1. Determine the correct size of wire or cable to use.
2. Decide whether the wire or cable will be buried, carried overhead on poles, or run in conduit.
3. Check the generator lead connections of the plant to see that they are arranged for the proper voltage output.

The information contained in the following paragraphs will help you in these tasks.

**CABLE SELECTION.**—If the wrong size conductor is used in the load cable, various troubles may occur. If the conductor is too small to carry the current demanded by the load, it will heat up and possibly cause a fire or an open circuit. Even though the conductor is large enough to carry the load current safely, its length might result in a lumped resistance that produces an excessive voltage drop. An excessive voltage drop results in a reduced voltage at the load end. This voltage drop should not exceed 3 percent for power loads, 3 percent for lighting loads, or 6 percent for combined power and lighting loads.

Select a feeder conductor capable of carrying 150 per cent of rated generator amperes to eliminate overloading and voltage drop problems. Refer to the National Electrical Code® tables for conductor ampacities. These tables are 310-16, 310-17, 310-18, and 310-19. You also should refer to the notes to ampacity tables following table 310-19.

**CABLE INSTALLATION.**—The load cable may be installed overhead or underground. In an emergency installation, time is the important factor. It may be necessary to use trees, pilings, 4 by 4s, or other temporary line supports to complete the installation. Such measures are temporary; eventually, you will have to erect poles and string the wire or bury it underground. If the installation is near an airfield, it may be necessary to place the wires underground at the

beginning. Wire placed underground should be direct-burial, rubber-jacketed cable; otherwise, it will not last long.

Direct burying of cable for permanent installation calls for a few simple precautions to ensure uninterrupted service. They are as follows:

1. Dig the trench deep enough so that the cable can be buried at least 18 inches (24 inches in traffic areas and under roadways) below the surface of the ground to prevent disturbance of the cable by frost or subsequent surface digging.
2. After laying the cable and before backfilling, cover it with soil free from stones, rocks, and so forth. That will prevent the cable from being damaged in the event the surrounding soil is disturbed by flooding or frost heaving.

## GENERATING PLANT OPERATIONS

When you are in charge of a generating station, you will be responsible for scheduling around-the-clock watches to ensure a continuous and adequate amount of electrical power. Depending on the number of operating personnel available, the watches are evenly divided over the 24-hour period. A common practice is to schedule 6-hour watches, or they may be stretched to 8-hour watches without working undue hardship on the part of the crew members. Watches exceeding 8 hours, however, should be avoided unless emergency conditions dictate their use.

The duties assigned to the personnel on generator watches can be grouped into three main categories: (1) operating the equipment, (2) maintaining the equipment, and (3) keeping the daily operating log. Operating and maintaining the generating equipment will be covered in the succeeding sections of this chapter, so for the present you can concentrate on the importance of the third duty of the station operator—keeping a daily operating log.

The number of operating hours are recorded in the generating station log. The log serves as a basis for determining when a particular piece of electrical equipment is ready for inspection and maintenance. The station log can be used in conjunction with previous logs to spot gradual changes in equipment condition that ordinarily are difficult to detect in day-to-day operation. It is particularly important that you impress upon your watch standers the necessity for taking accurate readings at periods specified by local operating conditions.

Ensure that watch standers keep their spaces clean and orderly. Impress on them the importance of keeping tools and auxiliary equipment in their proper places when not in use. Store clean waste and oily waste in separate containers. **OILY WASTE CONTAINERS ARE REQUIRED TO BE KEPT COVERED.** Care given to the station floor will be governed by its composition. Generally, it should be swept down each watch. Any oil or grease that is tracked around the floor should be removed at once.

## **Plant Equipment**

Setting up a power generator is only one phase of your job. After the plant is set up and ready to go, you will be expected to supervise the activities of the operating personnel of the generating station. In this respect, your supervision should be directed toward one ultimate goal—to maintain a continuous and adequate flow of electrical power to meet the demand. That can be accomplished if you have a thorough knowledge of how to operate and maintain the equipment and a complete understanding of the station's electrical systems as a whole. Obviously, a thorough knowledge of how to operate and maintain the specific equipment found in the generating station to which you are assigned cannot be covered here; however, general information will be given. It will be up to you to supplement this information with the specific instructions given in the manufacturers's instruction manuals furnished with each piece of equipment.

Similarly, familiarity with the station's electrical system as a whole can be gained only by a study of information relating specifically to that installation. This information can be found to some extent in the manufacturer's instruction manuals. You can obtain the greater part of it from the station's electrical plans and wiring diagrams. Remember, however, to supplement your study of the electrical plans and diagrams with an actual study of the generating station's system. In that way, the generators, switchgear, cables, and other electrical equipment are not merely symbols on a plan but physical objects whose location is definitely known and whose functions and relation to the rest of the system are thoroughly understood.

## **Single Plant Operation**

Connecting an electric plant to a de-energized bus involves two general phases: (1) starting the diesel engine and bringing it up to rated speed under control of the governor and (2) operating the switchboard

controls to bring the power of the generator onto the bus.

Different manufacturers of generating plants require the operator to perform a multitude of steps before starting the prime mover; for example, if a diesel engine is started by compressed air, the operator would have to align the compressed air system. This alignment would not be necessary if the engine is of the electric-start type. It is important that you, as the plant supervisor, establish a prestart checklist for each generating plant. The prestart checklist provides a methodical procedure for confirming the operational configuration of the generating plant; following this procedure assures that all systems and controls are properly aligned for operation.

The checklist should include, but is not limited to, the following:

1. Align ventilation louvers.
2. Check lube oil, fuel oil, and cooling water levels.
3. Ensure battery bank is fully charged.
4. Align electrical breakers and switches for proper operation of auxiliary equipment.
5. Check control panel and engine controls.
6. Select the proper operating position for the following controls for single plant operation.
  - Voltage regulator switch to UNIT or SINGLE position.
  - Governor switch to ISOCHRONOUS or SINGLE position.

**NOTE:** Adjust hydraulic governor droop position to 0.

- Voltage regulator control switch to AUTO position.

The prestart checklist should be completed in sequence before you attempt to start the generating plant.

Start the generating plant and adjust the engine rpm to synchronous speed. Adjust the voltage regulator to obtain the correct operating voltage. Set the synchronizing switch to the ON position and close the main circuit breaker. Adjust the frequency to 60 hertz with the governor control switch. Perform hourly operational checks to detect abnormal conditions and to ensure the generating set is operating at the correct voltage and frequency.

## Parallel Plant Operation

If the load of a single generator becomes so large that its rating is exceeded, you should add another generator in parallel to increase the power available for the generating station. Before two ac generators can be paralleled, the following conditions have to be fulfilled:

1. Their terminal voltages have to be equal.
2. Their frequencies have to be equal.
3. Their voltages have to be in phase.

When two generators are operating so that the requirements are satisfied, they are said to be in synchronism. The operation of getting the machines into synchronism is called synchronizing.

Generating plants may be operated in parallel on an isolated bus (two or more generators supplying camp or base load) or on an infinite bus (one or more generators paralleled to a utility grid).

One of the primary considerations in paralleling generator sets is achieving the proper division of load. That can be accomplished by providing the governor of the generator with speed droop. That would result in a regulation of the system. The relationship of REGULATION to LOAD DIVISION is best explained by referring to a speed versus load curve of the governor. For simplicity, we will refer to the normal speed as 100 percent speed and full load as 100 percent load. In the controlled system, we will be concerned with two types of governor operations: isochronous and speed droop.

The operation of the isochronous governor (0 percent speed droop) can be explained by comparing speed versus load, as shown in figure 3-3. If the governor were set to maintain the speed represented by line A and connected to an increasing isolated load, the speed would remain constant. The isochronous governor will maintain the desired output frequency, regardless of load changes if the capacity of the engine is not exceeded.

The speed-droop governor (100 percent speed droop) has a similar set of curves, but they are slanted, as shown in figure 3-4. If a speed-droop governor were connected to an increasing isolated load, the speed would drop (line A, fig. 3-4) until the maximum engine capacity is reached.

Now let's imagine that we connect the speed-droop governor (slave machine) to a utility bus so large that our engine cannot change the bus frequency (an

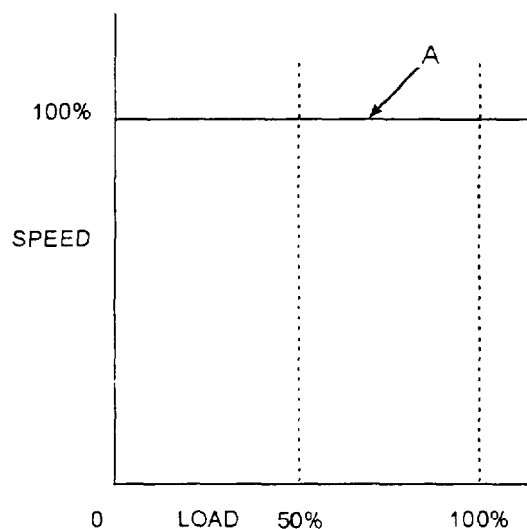


Figure 3-3.—Isochronous governor curve.

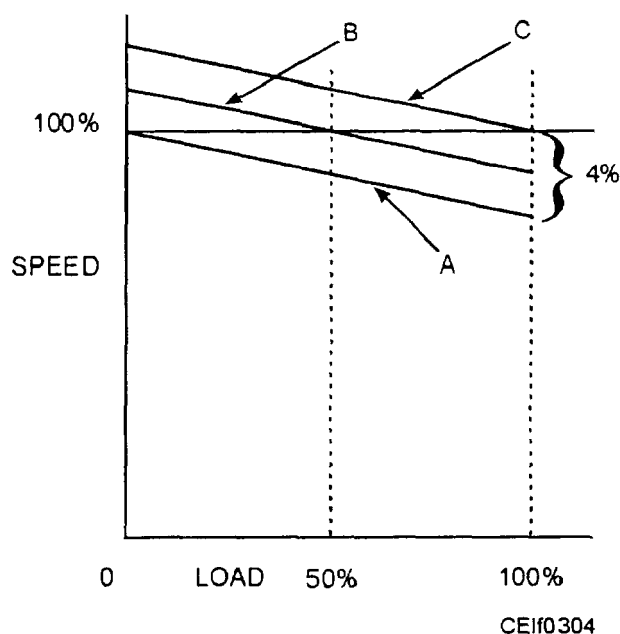


Figure 3-4.—Speed-droop governor curve.

infinite bus). Remember that the speed of the engine is no longer determined by the speed setting but by the frequency of the infinite bus. In this case, if we should change the speed setting, we would cause a change in load, not in speed. To parallel the generator set, we are required to have a speed setting on line A (fig. 3-4), at which the no-load speed is equal to the bus frequency. Once the set is paralleled, if we increase the speed setting to line B, we do not change the speed, but we pick up approximately a half-load. Another increase in speed setting to line C will fully load the engine. If the generator set is fully loaded and the main breaker is



opened, the no-load speed would be 4 percent above synchronous speed. This governor would be defined as having 4 percent speed droop.

Paralleling an isochronous governor to an infinite bus would be impractical because any difference in speed setting would cause the generator load to change constantly. A speed setting slightly higher than the bus frequency would cause the engine to go to full-load position. Similarly, if the speed setting were slightly below synchronous speed, the engine would go to no-load position.

Setting speed droop on hydraulic governors is accomplished by adjusting the speed-droop knob located on the governor body. Setting the knob to position No. 5 does not mean 5 percent droop. Each of the settings on the knob represents a percentage of the total governor droop. If the governor has a maximum of 4 percent droop, the No. 5 position would be 50 percent of 4 percent droop. Setting speed droops on solid-state electronic governors is accomplished by placing the UNIT-PARALLEL switch in the PARALLEL position. The governor speed droop is factory set, and no further adjustments are necessary.

**ISOLATED BUS OPERATION.**—In the following discussion, assume that one generator, called the master machine, is operating and that a second generator, called the slave machine, is being synchronized to the master machine. Governor controls on the master generator should be set to the ISOCHRONOUS or UNIT position. The governor setting on the slave generator must be set to the PARALLEL position.

**NOTE:** The hydraulic governor droop setting is an approximate value. Setting the knob to position No. 5 will allow you to parallel and load the generator set. Minor adjustments may be necessary to prevent load swings after the unit is operational.

When you are paralleling in the droop mode with other generator sets, the governor of only one set may be in the isochronous position; all others are in the droop position. The isochronous set (usually the largest capacity set) controls system frequency and immediately responds to system load changes. The droop generator sets carry only the load placed on them by the setting of their individual speed controls. Both voltage regulators should be set for parallel and automatic operation.

The slave machine is brought up to the desired frequency by operating the governor controls. It is preferable to have the frequency of the slave machine

slightly higher than that of the master machine to assure that the slave machine will assume a small amount of load when the main circuit breaker is closed. Adjust the voltage controls on the slave machine until the voltage is identical to that of the master machine. Thus two of the requirements for synchronizing have been met: 'frequencies are equal and terminal voltages are equal.

There are several methods to check generator phase sequence. Some generator sets are equipped with phase sequence indicator lights and a selector switch labeled "GEN" and "BUS." Set the PHASE SEQUENCE SELECTOR SWITCH in the BUS position, and the "1-2-3" phase sequence indicating light should light. (The same light must light in either GEN or BUS position.) If "3-2-1" phase sequence is indicated, the slave machine has to be shut down, the load cables isolated, and two of the load cables interchanged at their connection to the load terminals.

Another method to verify correct phase sequence is by using the synchronizing lights. When the synchronizing switch is turned on, the synchronizing lights will start blinking. If the synchronizing lights blink on simultaneously and off simultaneously, the voltage sequences of the two machines are in phase. The frequency at which the synchronizing lights blink on and off together indicates the different frequency output between the two machines. Raise or lower the speed of the slave machine until the lights blink on together and off together at the slowest possible rate. If the synchronizing lights are alternately blinking (one on while the other is off), the voltage sequence of the two machines is not in phase. Correct this condition by interchanging any two of the three load cables connected to the slave machine.

Some of the portable generators being placed in the NMCB Table of Allowances (TOA) are equipped with a permissive paralleling relay. This relay, wired into the main breaker control circuit, prevents the operator from paralleling the generator until all three conditions have been met.

Now that all three paralleling requirements have been met, the slave machine can be paralleled and loaded.

If a synchroscope is used, adjust the frequency of the slave machine until the synchroscope pointer rotates clockwise slowly through the ZERO position (twelve o'clock). Close the main circuit breaker just before the pointer passes through the ZERO position. To parallel using synchronizing lights, wait until the

lamps are dark; then, while the lamps are still dark, close the main circuit breaker and turn off the synchronizing switch.

After the main breaker has been closed, check and adjust the load distribution by adjusting the governor speed control. Maintain approximately one-half load on the master machine by manually adding or removing the load from the slave machine(s). The master machine will absorb all load changes and maintain correct frequency unless it becomes overloaded or until its load is reduced to zero.

The operator also must ensure that all generating sets operate at approximately the same power factor (PF). PF is a ratio, or percentage, relationship between watts (true power) of a load and the product of volts and amperes (apparent power) necessary to supply the load. PF is usually expressed as a percentage of 100. Inductive reactance in a circuit lowers the PF by causing the current to lag behind the voltage. Low PFs can be corrected by adding capacitor banks to the circuit.

Since the inductive reactance cannot be changed at this point, the voltage control rheostat has to be adjusted on each generator to share the reactive load. This adjustment has a direct impact on the generator current, thus reducing the possibility of overheating the generator windings.

PF adjustment was not discussed in the “Single Plant Operation” section because a single generator has to supply any true power and/or reactive load that may be in the circuit. The single generator must supply the correct voltage and frequency regardless of the power factor.

**INFINITE BUS OPERATION.**—Paralleling generator sets to an infinite bus is similar to the isolated bus procedure with the exception that all sets will be slave machines. The infinite bus establishes the grid frequency; therefore, the governor of each slave machine has to have speed droop to prevent constant load changes.

### Emergency Shutdown

In the event of engine overspeed, high jacket water temperature, or low lubricating oil pressure, the engine may shut down automatically and disconnect from the main load by tripping the main circuit breaker. In addition, an indicator may light or an alarm may sound to indicate the cause of shutdown. After an emergency shutdown and before the engine is returned to

operation, the cause of shutdown should be investigated and corrected.

**NOTE:** It is important to check the safety controls at regular intervals to determine that they are in good working order.

### Basic Operating Precautions

The order that you post in the station for the guidance of the watch standers should include a general list of operating rules and electrical safety precautions. **BE SURE YOU ENFORCE THEM!**

The important operating rules are relatively few and simple. They are as follows:

1. Watch the switchboard instruments. They show how the system is operating; and they reveal overloads, improper division of kilowatt load or reactive current between generators operating in parallel, and other abnormal operating conditions.
2. Keep the frequency and voltage at their correct values. A variation from either will affect, to some extent at least, the operation of the electrical equipment of the base. This result is especially true of such equipment as teletypewriters or electrical clocks. An electrical clock and an accurate mechanical clock should be installed together at the generating station so that the operators can keep the generators on frequency.
3. Use good judgment when reclosing circuit breakers after they have tripped automatically; for example, generally the cause should be investigated if the circuit breaker trips immediately after the first reclosure. However, reclosing of the breaker the second time may be warranted if immediate restoration of power is necessary and there was no excessive interrupting disturbance when the breaker tripped. It should be kept in mind, however, that repeated closing and tripping may damage the circuit breaker as well as the overload vault area, thus increasing the repair or replacement work.
4. Do not start a plant unless all its switches and breakers are open and all external resistance is in the exciter field circuit.
5. Do not operate generators at continuous overload. Record the magnitude and duration of the overload in the log; record any unusual conditions or temperatures observed.
6. Do not continue to operate a machine in which there is vibration until the cause is found and corrected. Record the cause in the log.

The electrical safety precautions that should be observed by the station personnel are as follows:

1. Treat every circuit, including those as low as 24 volts, as a potential source of danger.
2. Except in cases of emergency, never allow work on an energized circuit. Take every precaution to insulate the person performing the work from ground. That may be done by covering any adjacent grounded metal with insulating rubber blankets. In addition, provide ample illumination, cover working metal tools with insulating rubber, station men at appropriate circuit breakers or switches so that the switchboard can be de-energized immediately in case of emergency, and make sure all personnel are qualified to render first aid (including CPR) for electric shock.

## **POWER PLANT MAINTENANCE**

Inspection and servicing procedures covered in this chapter are rather general. In most cases, they can be applied to any electrical power generator that you install. You realize, of course, that there are other special installation details that pertain only to the particular generator you happen to be working on. Because of the many different types of generators, certain instructions are applicable only to specific types of generators; therefore, you should consult the manufacturer's instruction manuals for these details.

Power plant maintenance can be divided into two general categories: operator maintenance and preventive maintenance.

### **Operator Maintenance**

Operator maintenance includes the hourly, daily, and weekly maintenance requirements recommended

in the manufacturer's literature. Some operator maintenance and routine checks include the following:

- Bring oil level to the high mark on the dip stick.
- Free movement of ventilation louvers.
- Drain water and sediment from strainers and filters.
- Maintain level of coolant.
- Check radiator and coolant hoses for leaks.
- Check battery electrolyte level.
- Check all switches for proper operation.
- Drain water from fuel tank.
- Fill fuel tank as required with appropriate diesel fuel.
- Check fuel tank for leaks.

Log all operator maintenance in the operations log book when it is completed.

### **Preventive Maintenance**

Preventive maintenance includes the monthly, quarterly, semiannual, and annual maintenance checks recommended in the manufacturer's literature. The maintenance supervisor is responsible for establishing a maintenance schedule to ensure the preventive maintenance is performed. A maintenance log book should be established for each generator plant and all maintenance checks recorded. The operation log book should be reviewed periodically to ensure that all preventive maintenance recommended by engine operating hours is scheduled; for example, the schedule of engine lube oil and filter replacement is normally based on hours of operation.

